



GREENHOUSE GAS EMISSION ANALYSIS FOR HEATED PAVEMENT SYSTEM

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Outline

- Background
- Objectives
- Methodology
- Results and Discussions
- Summary



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- Global warming is a serious and well-known environmental issue



<http://www.telegraph.co.uk/science/science-news/10837146/Climate-change-science-has-become-blind-to-green-bias.html>



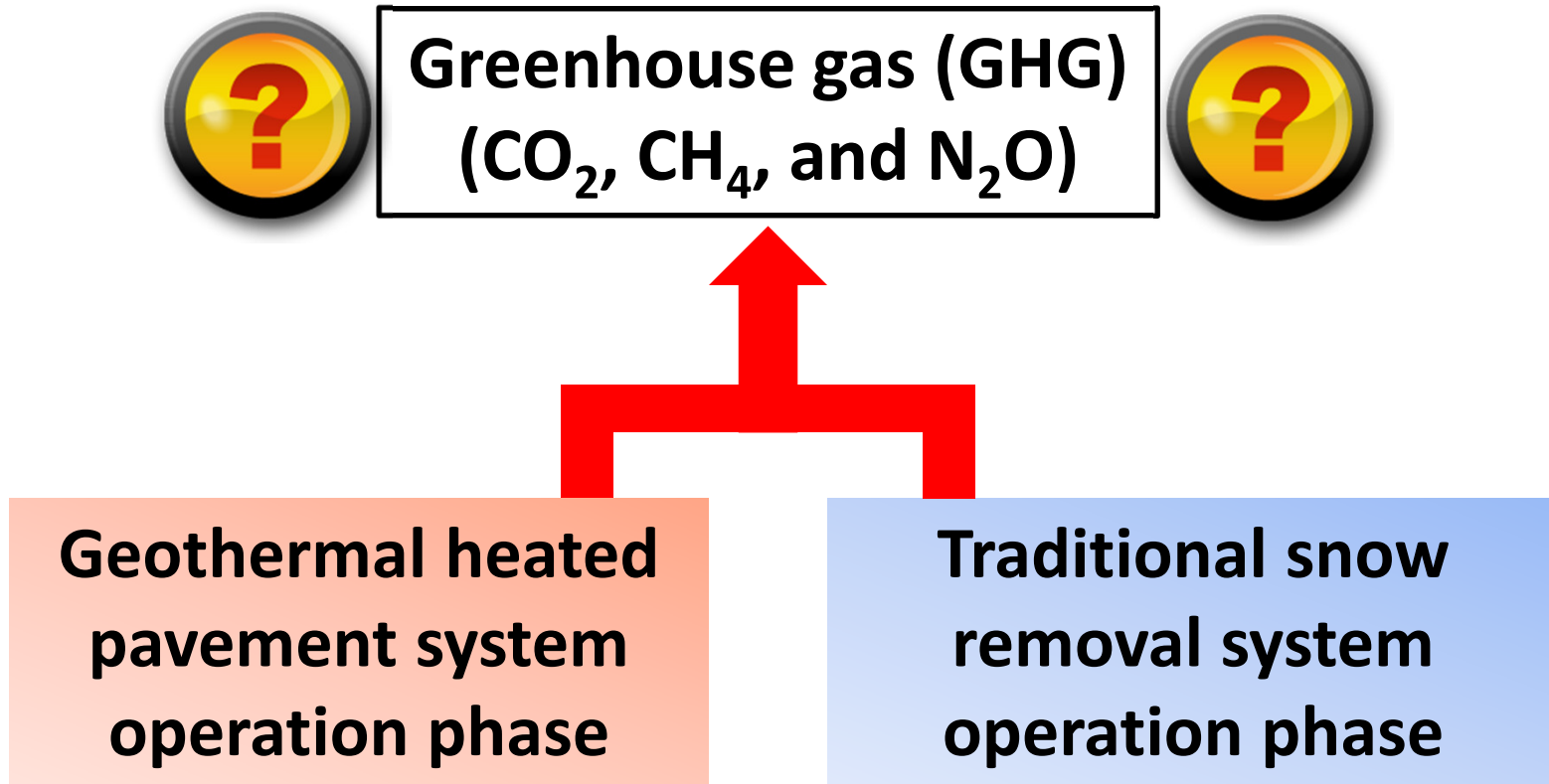
<http://www.dailymail.co.uk/health/article-2596811/Natural-disasters-trigger-broken-heart-Extreme-stress-caused-earthquakes-hurricanes-weaken-heart-muscle.html>

- Innovation is needed in reducing/mitigating carbon emissions from man-made processes and systems



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GHG	CO ₂	CH ₄	N ₂ O
Global-warming potential	1	25	298

GWP time horizon: 100 years

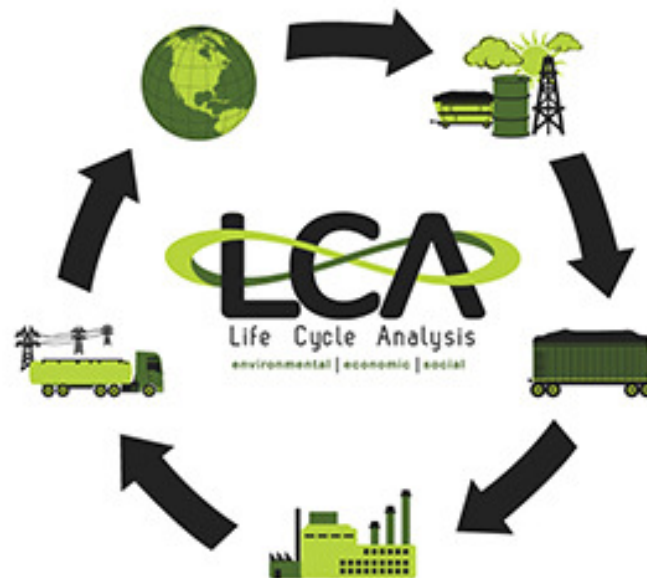


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Life Cycle Assessment (LCA)

- LCA is a well-developed assessment methodology for estimating and analyzing the environmental impacts of products from raw material to end product



<http://www.netl.doe.gov/research/energy-analysis/life-cycle-analysis>

Assumptions of Snow and Airport Runway Conditions

- Airport Runway Area = 1.8 million ft²
- Snow Fall = 1 in./day



<http://www.telegraph.co.uk/news/picturegalleries/uknews/8186730/Frozen-Britain-travel-chaos-in-Scotland-as-snow-and-sub-zero-temperatures>

Traditional Snow Removal System Model



<http://media3.washingtonpost.com/wp-srv/photo/gallery/091218/GAL-09Dec18-3388/media/PHO-09Dec18-194462.jpg>



https://c2.staticflickr.com/6/5190/5658141911_2ddf2897df_z.jpg



<http://www.team-eagle.ca/wp-content/uploads/2011/06/TylerIce-013.jpg>



Methodology

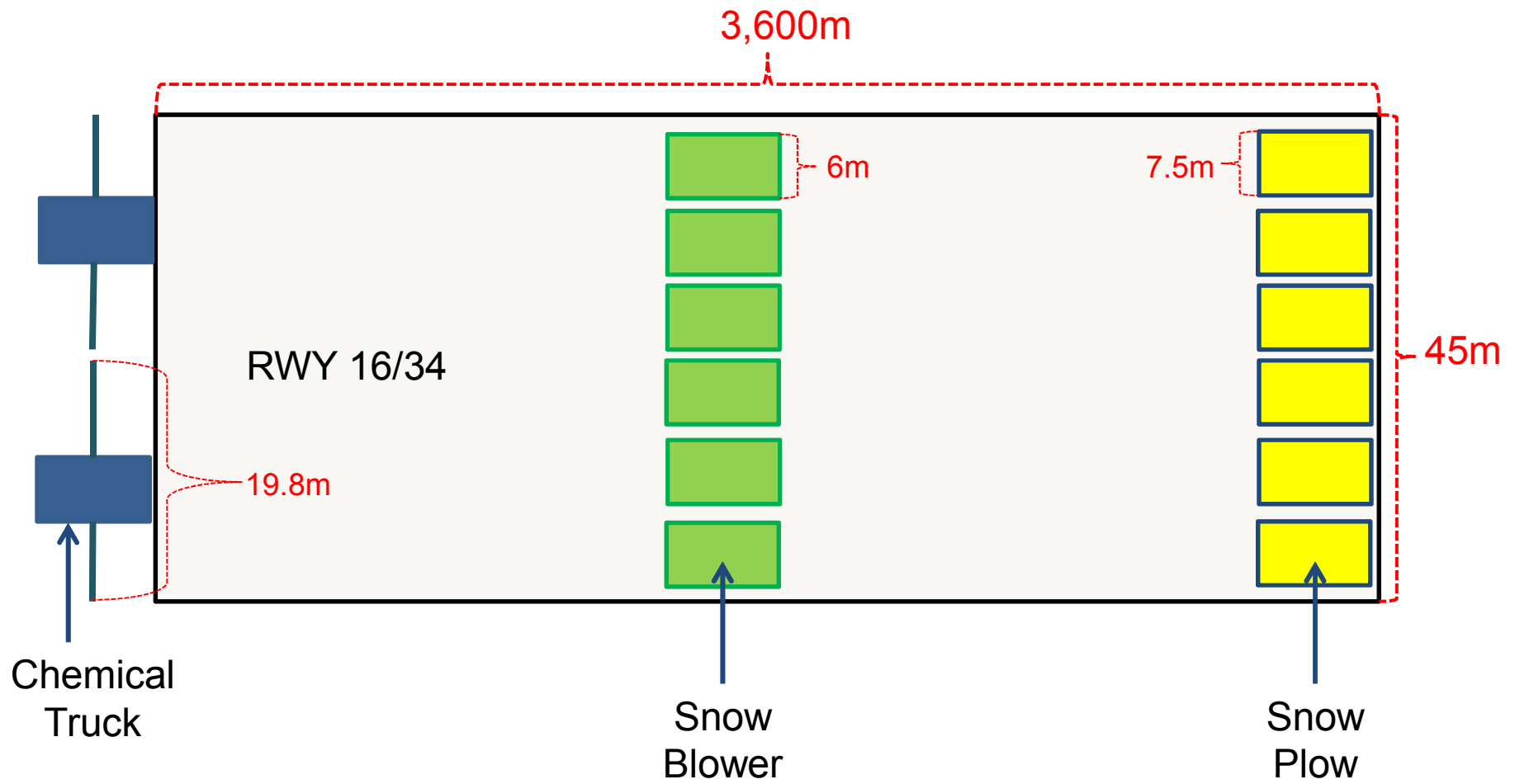
Snow Removal Equipment Information

- Snow Plow
 - Clearing width: 7.5 m
 - Engine: 708kW

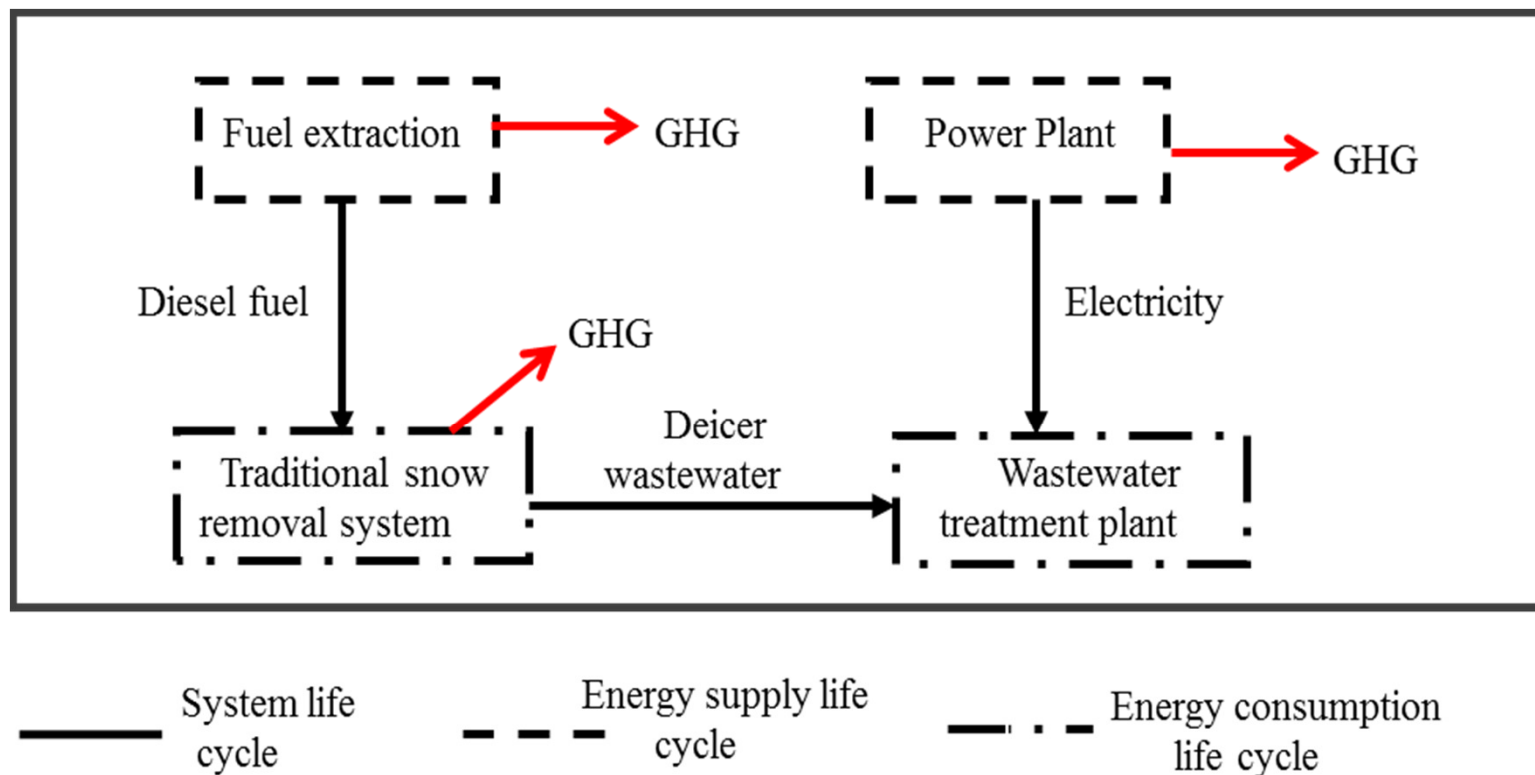
- Snow Blower
 - Capacity: 7,000t per blower per hour
 - Engine: 410kW

- De-icer Sprayer
 - Clearing width: 19.8 m
 - Engine: 300kW

Airport Snow Removal Strategy Assumption:



System Boundary of Traditional Snow Removal System





Equations for Calculating Snow Removal Equipment
GHG Emission:

$$FC = RP \times 0.3 \times LF$$

$$GHG\ emission = FC \times 0.00268$$



Deicing Application

- Deicing:
 - 1 gallon/1,000ft² (50g/m²) near 32°F (0°C)
 - 3 gallon/1,000ft² (150g/m²) near 10°F (-12°C)

- Anti-icing
 - 0.5 gallon/1,000ft² (25g/m²)



Specific Gravity of Common Deicing Fluid Components

Fluid Component	Specific Gravity (dimensionless)
Water	1.000
Ethylene Glycol	1.119
Propylene Glycol	1.036
Urea	1.323

A 50% ethylene glycol deicing fluid is considered as an example. The weight of the ethylene glycol component, following the above equation, is 8.345 pounds/gallon x (50/100) x 1.119 = 4.67 pounds ethylene glycol per gallon of fluid.



Methodology

Ethylene glycol deicer COD

- Deicing Compound: EG
- ThOD (Moles of Oxygen per Mole of Deicing Compound)=2.5
- COD Load (lbs)=Chemical (lbs) ×Chemical Molecular Weight (mol/g) ×ThOD ×O₂ Molecular Weight (g/mole)

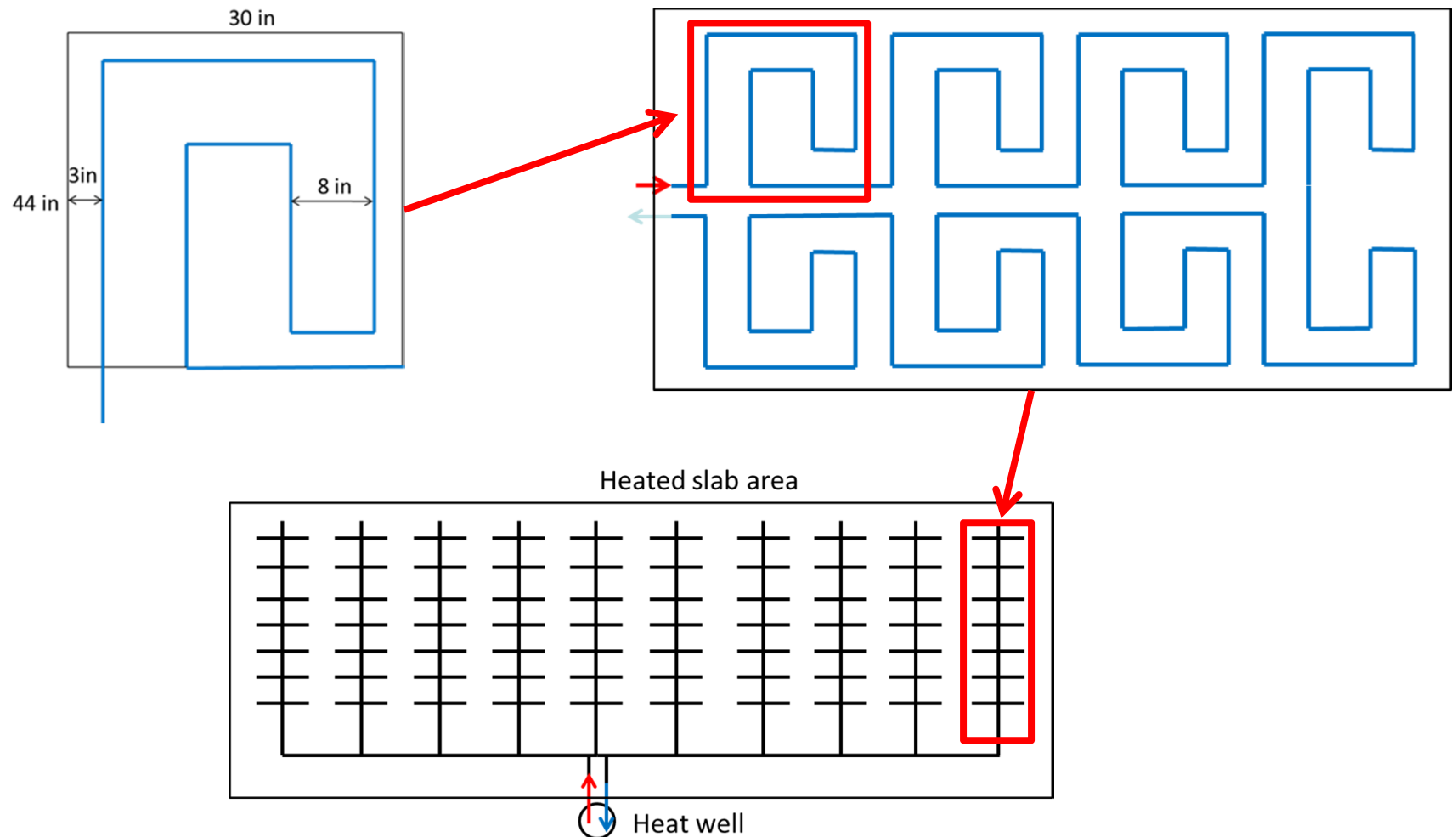
Energy Consumption of Wastewater Treatment: (Brewing and Beverage Industry No 1/2010)

- **Aerobic** system is typically **0.7-1.0** kWh/kg COD
- **Anaerobic** system is **0.07-0.10** kWh/kg COD

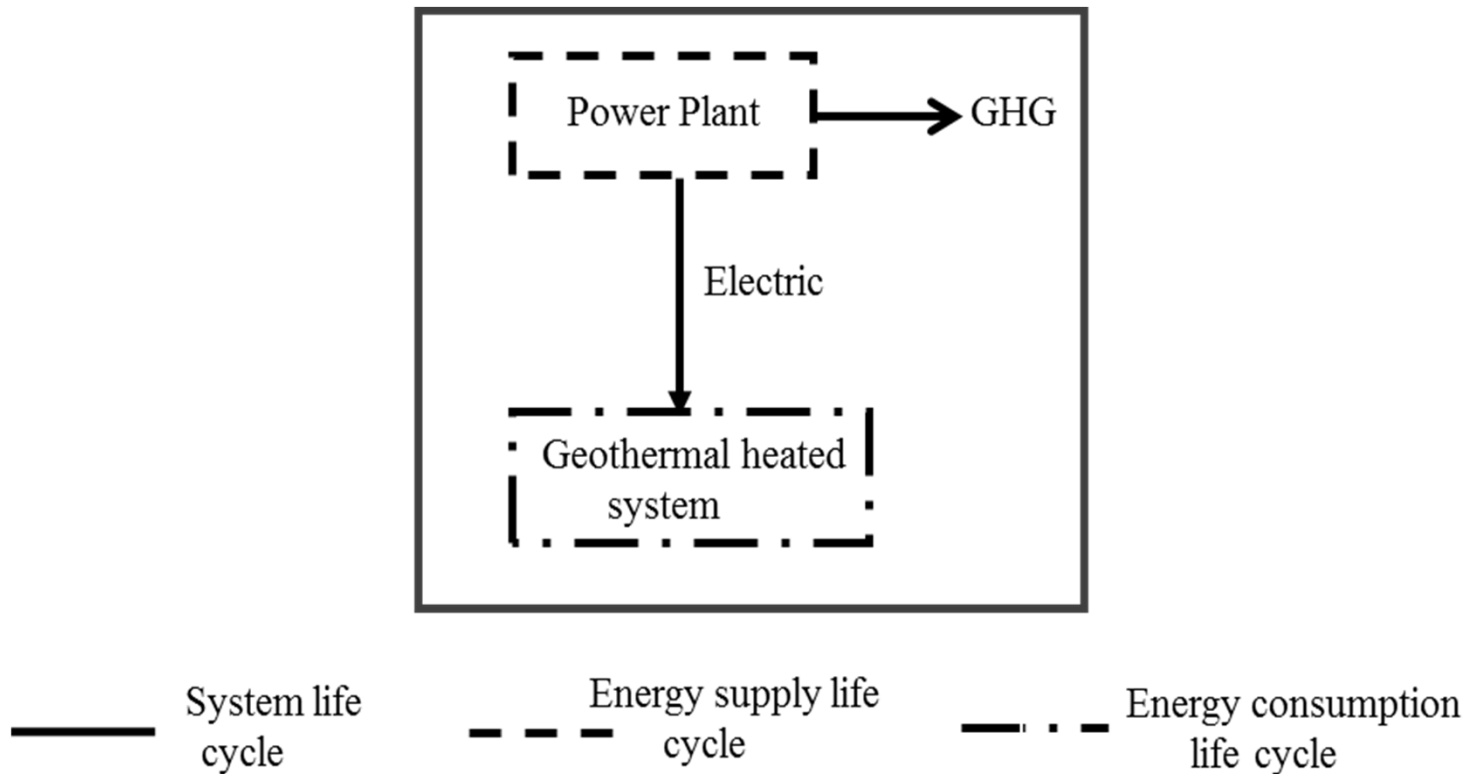


<http://www.aecom.com/What+We+Do/Water/Market+Sectors/Wastewater>

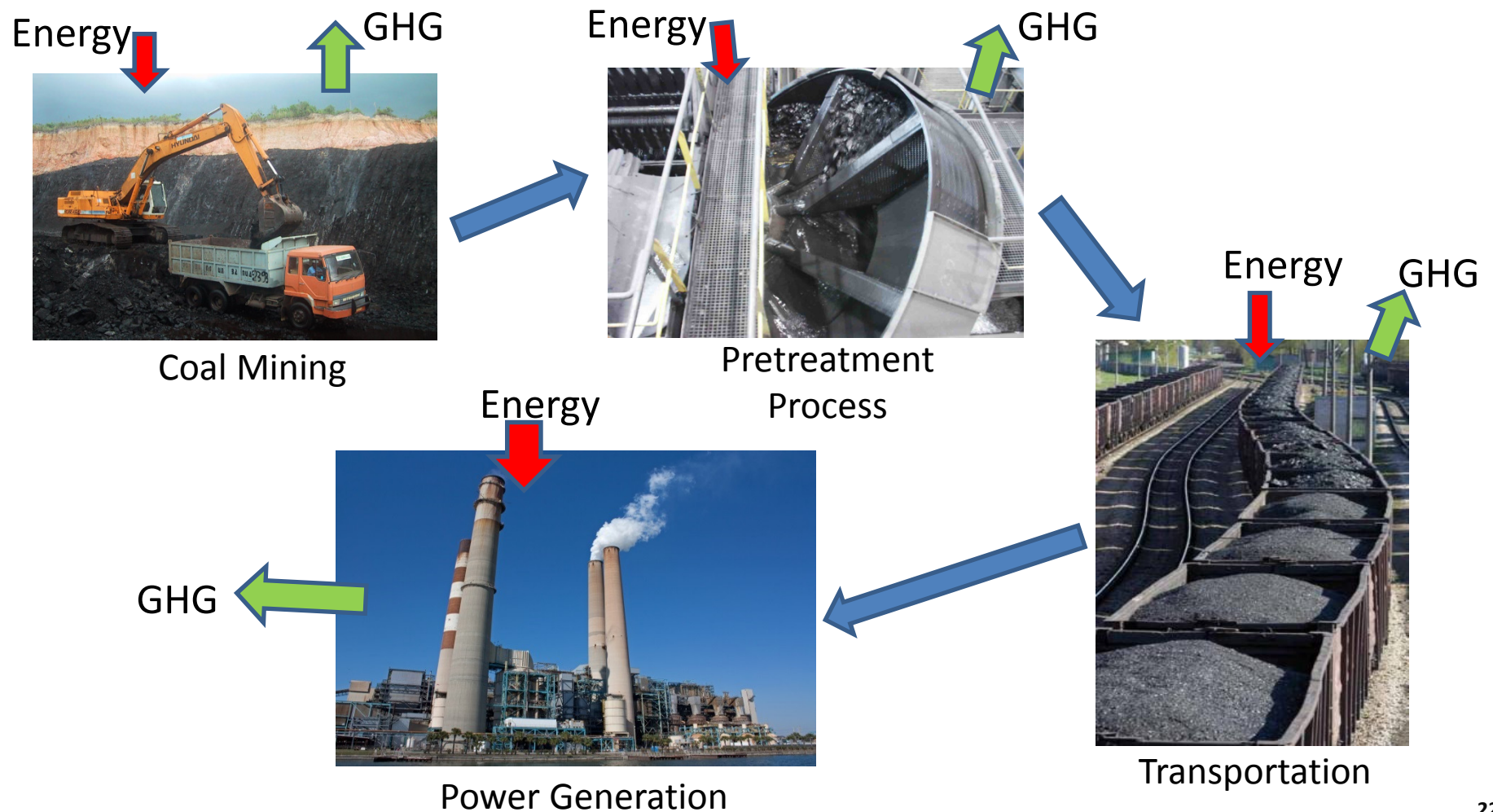
Geothermal Heated Pavement System Model



System Boundary of Geothermal Heated Pavement System



GHG Emission: Power Plant Life Cycle





GHG Emission: Power Plant Life Cycle

Coal fired-power plant	Natural gas fired-power plant	Fuel fired-power plant
Coal Mining	Drilling	Crude Oil Extraction
Pretreatment Process	Pretreatment Process	Crude Oil Refining
Transportation	Transportation	Transportation
Power Generation	Power Generation	Power Generation

GHG Emission: Power Plant Life Cycle - Coal Power Plant

Life Cycles of Coal Power Plant		GHG Emission Factor, kgCO ₂ eq/kWh	Percentage %	Assumptions	Data Sources
Surface Mining		7.02×10^{-3}	0.70	Illinois No. 6 coal as an example; electricity demand: 0.0143 kWh/kg of coal; diesel oil demand: 269 m ³ /MMT of coal; transportation of diesel oil GHG emission: 2.7 kgCO ₂ eq/L; 0.54 kg coal/kWh electricity produced	Spath, Pamela L., et al (1999) [27]; CDM-SSC-PDD (2006) [28]; EIA FAQ (2014) [29]
Coal Washing		1.03×10^{-4}	0.01	Jig washing is the technique used in this LCA.	Spath, Pamela L., et al (1999) [27]
Coal Transportation	Shipping	0.10	10.10	Distance from mining to power plant: 434 km; GHG emission: 0.43 kgCO ₂ eq/t·km	G. Chen, et al (2013) [30]
	Railway	2.59×10^{-4}	0.03	Distance from mining to power plant: 48 km; GHG emission: 0.01 kgCO ₂ eq/t·km	G. Chen, et al (2013) [30]
Grid Electricity Production		0.88	89.20	Data from US Energy Information Administration EIA-1605 is used	US Energy Information Administration EIA-1605 (2010) [31]
Whole Life Cycle		0.99	100		



Methodology

GHG Emission: Energy Production Phase - Natural Gas Power Plant

Life Cycles of Coal Power Plant	GHG Emission Factor kgCO ₂ eq/kWh	Percentage %	Assumptions	Data Sources
Natural gas extraction	4.27×10^{-3}	1.01	Natural gas density: 0.042 lb/ft ³ ; 2-phases 95%-efficiency compressor is applied, power demand: 187 Hp per MMCF of natural gas	National Energy Technology Laboratory (2000) [32].
Natural gas pretreatment	8.54×10^{-5}	0.02	Engines of natural gas liquefaction and liquefied natural gas (LNG) regasification runs at 75% load	National Energy Technology Laboratory (2000) [32].
Liquefied natural gas transportation	1.35×10^{-5}	0.0032	LNG tanker berthing and LNG transportation are included; total distance: 482 km by shipping	G. Chen, et al (2013) [30].
Grid electricity production	0.42	98.97	Specific volume of natural gas: 23.8 ft ³ /lb; auxiliary boiler natural gas consumption: 0.16 kg/MWh	National Energy Technology Laboratory (2000) [32].
Whole life cycle	0.42	100		



GHG Emission: **Energy Production Phase** - **Fuel Fired Power Plant**

- Since oil fired power plant carbon emission factor highly depends on a particular (site-specific) power plant, this study assumed 0.778kgCO₂eq/kWh.

GHG Emission: **Energy Production Phase - GHG emission factor of coal fired power plant**

- Coal fired power plant carbon emission factor:
 - **0.989** kgCO²/kWh
- Natural gas fired power plant carbon emission factor:
 - **0.420** kgCO²/kWh
- Fuel fired power plant carbon emission factor:
 - **0.778** kgCO²/kWh

Equations Used in Energy Demand Calculation:

$$q_o = q_s + q_m + A_r(q_e + q_h)$$

q_o (Btu/h·ft ²)	q_s (Btu/h·ft ²)	q_m (Btu/h·ft ²)	A_r	q_e (Btu/h·ft ²)	q_h (Btu/h·ft ²)
204.71	9.82	74.6	0.7	0.25	171.6

$$E = 0.00095 \times P \times m \times cp \times (\Delta T)$$

$$Hp = Q \times H / 3960$$



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GHG Emissions of Traditional Snow Removal System Applied in Airport Runway Snow Removal Life Cycle

Life cycle stages	GHG Emissions /t		
Snow removal	0.62		
Fuel extraction	0.017		
Wastewater treatment	6.83 ¹	2.90 ²	5.37 ³
Total	7.47	3.53	6.01

Note: ¹electricity generated by coal power plant; ²electricity generated by natural gas power plant; ³electricity generated by diesel oil power plant.

GHG Emissions of Geothermal Heated System Using Electricity for Operation

Electricity form	Coal	Natural Gas	Diesel Oil
GHG emissions /t	5.46	2.32	4.30

GHG Emissions of Geothermal Heated Pavement System and Traditional Snow Removal System Operation Phase

Total CO2 Emission /t	Electricity Coal	Electricity Natural Gas	Electricity Fuel Oil
Geo-system	5.47	2.32	4.30
Traditional	7.47	3.53	6.00



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Findings

- Most of the GHG emissions in the traditional snow removal system are from deicer wastewater treatment plant which uses aerobic biological method
- Based on the assumptions and specific conditions considered in this study, a geothermal heated pavement system using electric pump to run the system has lower GHG emissions than a traditional snow removal system in removing 1 inch of snow from airport runway surface at an ambient temperature of -6 °F



Summary

- Recommendations
 - Future research should investigate the influence of the following on GHG emissions
 - Different weather conditions
 - Different snow removal equipment and strategies
 - Other potential factors
 - Deicer chemicals on airport pavement lead to more frequent repairs. Construction phase and maintenance phase of geothermal heated pavement systems can be included to gain a better understanding of GHG emissions from snow removal system life cycle



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- Although the FAA has sponsored this project, it neither endorses nor rejects the findings of this research
- The presentation of this information is in the interest of invoking comments by the technical community on the results and conclusions of the research



Thank You!
Questions & Comments?